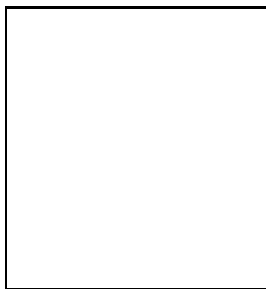


New trends in modern event generators

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Abstract

Some features of modern simulation tools for high-energy physics are reviewed.

1 Introduction: The next generation of event generators

In the past decades, event generators have become increasingly important for the planning of collider experiments and analyses of their data. In the LHC era this trend will become even more pronounced, since many of the interesting signals expected at the LHC - such as signals for the Higgs boson or alternative electroweak symmetry breaking mechanisms, supersymmetry, etc. - are severely hampered by large backgrounds, with a significant influence of QCD. Thus, the success of the LHC probably rests on a precise understanding of these backgrounds. Examples for this include the effect of the central jet-veto in vector boson fusion, producing the Higgs boson, and in multi-jet backgrounds to SUSY searches. In view of this, it is obvious that many of the old tools need to be replaced by newer, and better ones, such as Pythia8 [1], Herwig++ [2], and SHERPA [3]. Their ongoing construction in fact reflects increased experimental needs. In many cases, they therefore incorporate new, better simulation methods, many of which are connected to the systematic inclusion of higher-order QCD-corrections.

2 Parton level: Calculation of signal and background

Many of the apparent improvements of current event generators rely on the inclusion of higher-order corrections; one method is to use multi-leg tree-level matrix elements (MEs) as a base for simulation. There are a number of such tools on the market, which either evaluate Feynman graphs using the helicity method (for instance [4]) or recursion relations, e.g. [5].

Process	Cross section	time (helicity)	time (MHV)
$jj \rightarrow jj$	$745.85 \mu\text{b} \pm 0.10\%$	66 s	44 s
$jj \rightarrow jjj$	$81.274 \mu\text{b} \pm 0.20\%$	1400 s	166 s
$gg \rightarrow gggg$	$10.145 \mu\text{b} \pm 0.23\%$	90 ks	0.6 ks
$jj \rightarrow jjjj$	$23.208 \mu\text{b} \pm 0.26\%$	210 ks	5.8 ks
$gg \rightarrow ggggg$	$2.6915 \mu\text{b} \pm 0.15\%$	-	17 ks
$jj \rightarrow jjjjj$	$7.3294 \mu\text{b} \pm 0.17\%$	-	122 ks

Table 1: Performance of different calculational methods for multi-leg QCD matrix elements. Time is given for the calculation of 310000 phase space points. Clearly, the CSW recursion relations (here labeled with MHV) are superior in performance; the fact that only up to two quark lines have been included in the respective algorithm, has negligible influence on the final result.

$gg \rightarrow ggg$	$jj \rightarrow jjj$	$gg \rightarrow gggg$	$jj \rightarrow jjjj$	$gg \rightarrow ggggg$	$jj \rightarrow jjjjj$
5.8%	1.6%	2.0%	0.5%	0.9%	0.2%

Table 2: Unweighting efficiencies obtained with the integration in AMEGIC++.

However, apart from being able to calculate the MEs quickly, also the ability to integrate efficiently over the final state particles' phase space is a major obstacle for a satisfying performance of such tools.

In the following, some results addressing both issues, are presented, serving as illustrative examples for current performances. In Tab. 1, the performance of the helicity method is compared to the performance of the CSW recursion relations [6]. For pure QCD processes both approaches have been implemented in the parton level generator AMEGIC++ [7], which is a central part of SHERPA. The phase space integration and the corresponding unweighting efficiencies rely on an integrator based on a hierarchical antenna generation (HAAG) [8], which has been further improved with VEGAS [9]. Results for the unweighting efficiencies are displayed in Tab. 2.

3 From parton to hadron level

For experimental analyses, however, parton level results, discussed in the previous section, are of limited interest only. This is due to the fact that the experimental discussion of jets is based on hadrons rather than on partons. At the moment, the transition from partons to hadrons can be described with phenomenological models only, which depend on tunable parameters. In order to guarantee the validity of such a tuned parameter set, the partons entering these models should have comparable distances in phase space. Ultimately, this is what the parton shower (PS), modelling secondary Bremsstrahlung emissions, is responsible for.

When comparing matrix elements (MEs) with the PS, it becomes apparent that they perform best in different regimes of particle creation. While MEs essentially are well-suited to describe hard, large-angle emissions, taking interferences into account, the PS covers especially soft and collinear emissions, resumming corresponding large logarithms. It is therefore natural to try to combine both descriptions into a unified one, employing the best of both approaches for an improved simulation. The catch in so doing is to avoid double-counting of emissions into the same region of phase space and to preserve the correct treatment of leading logarithms. An algorithm satisfying these requirements has been presented in [10] for the case of $e^+e^- \rightarrow$ hadrons, where its accuracy up to next-to leading logarithmic order has been proven. An extension to hadronic collisions has been presented in [11]. This algorithm aims at a description of all jet emissions correct at tree level plus leading logarithms, with all soft and collinear emissions correctly taken care of in the PS. To achieve this, parton emission is separated into two regimes, one for jet production and one for jet evolution, through a k_\perp -algorithm [12]. Jets are then produced according to tree level MEs, the corresponding configurations are re-weighted with analytical Sudakov form factors and running α_s weights. In the PS, production of additional hard jets is vetoed. Altogether, this algorithm has been implemented

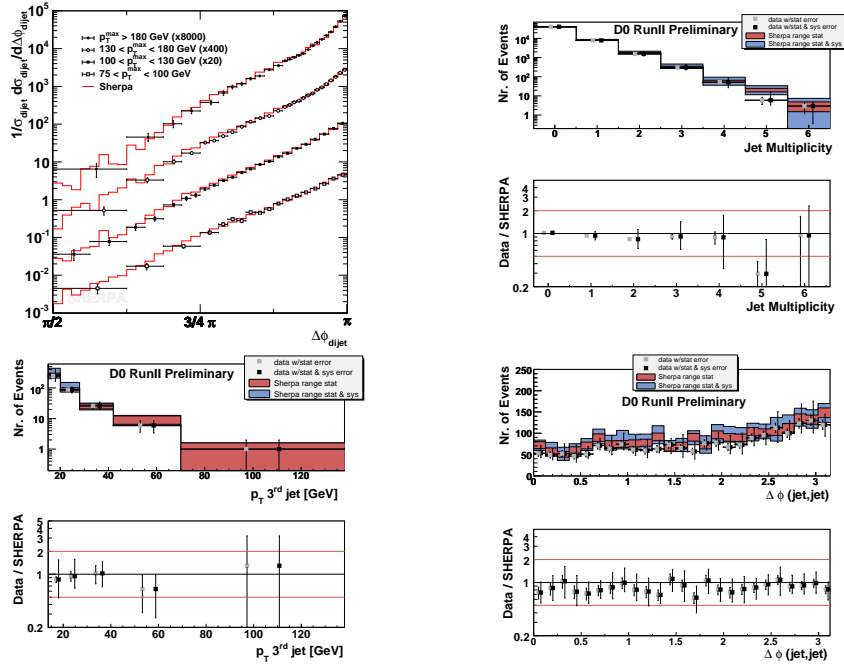


Figure 1: The azimuthal decorrelation of jets in QCD events (upper left panel), and jet multiplicities (upper right panel), the transverse momentum of the third-hardest jet (lower left panel) and the azimuthal correlation of the two leading jets (lower right panel) in associated Z +jet production. All measurements by DØ at Tevatron, Run II, and compared with the results from SHERPA.

in a process-independent way in SHERPA [3], allowing for careful validation and cross checks with experimental data or other calculations [13].

As a non-trivial check of the quality in describing the QCD radiation pattern through the merging approach, consider the azimuthal decorrelation of jets in $p\bar{p}$ collisions at the Tevatron, Run II, as presented in [14]. This observable effectively tests additional radiation, both hard and soft, in inclusive QCD dijet production. The agreement of the results of a SHERPA simulation with the experimental results is remarkable, cf. the upper left panel of Fig. 1. A prime example for the predictive power of the merging approach of SHERPA is the case of inclusive Z as measured by the DØ collaboration at Tevatron, Run II [15]. There, SHERPA is not only perfectly capable to predict the relative multiplicities of associated jets, cf. the upper right panel of Fig. 1; it also yields an improved description of the jet kinematics. This is illustrated in the lower panels of Fig. 1, where the transverse momentum distribution of the third-hardest jet (left) and the azimuthal correlation of the two leading jets (right) are displayed. In so doing, its abilities stretch beyond those of other, more traditional event generators, which do not rely on such a merging approach.

4 Modelling hadron decays

Another improvement of modern event generators when compared to traditional ones rests in the description of hadron decays and decay chains. Apart from the inclusion of spin correlations [16], modelling the effect of interferences in decay chains, apparent refinement of the simulation can be achieved by using better form factor models in decays, leading to non-flat phase space distributions and by an upgraded description of mixing effects, like, e.g. $B\bar{B}$ mixing. Some of these refinements are exemplified in Fig. 2. There, in the left panel, the effect of different form factor models [17] on $m_{\pi\pi}$ in decays $\tau \rightarrow \pi\pi\nu_\tau$ are compared with experimental data from [18], whereas in the right panel the asymmetry of $J/\Psi K_S$ final states in B decays is displayed.

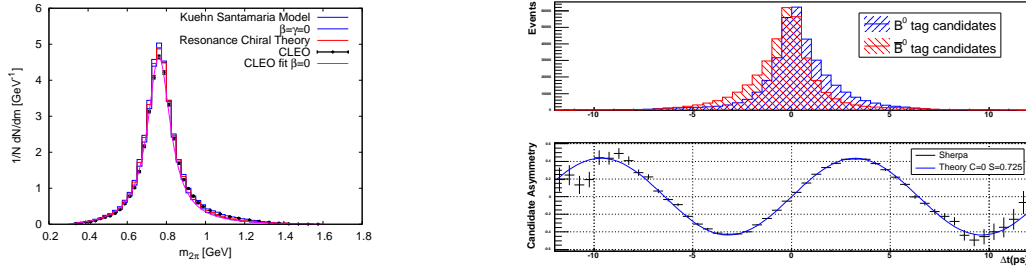


Figure 2: The impact of different form factor models on the decay $\tau \rightarrow \pi\pi\nu_\tau$ (left panel) and the simulation of $B\bar{B}$ mixing on the asymmetry of $J/\Psi K_S$ final states in B decays (right panel); results from SHERPA.

5 Conclusions

In this contribution, the need for new simulation tools in preparation for a successful LHC era has been motivated. These new tools become mandatory due to the abundance of backgrounds, shadowing potentially interesting signals. An apparent feature of modern event generators, improving traditional ones rests in the systematic inclusion of higher-order QCD corrections through merging or matching algorithms. One of them has been shortly discussed, and results obtained with it have been presented. In order to realise tree-level merging algorithms, multi-leg tree level parton level event generators are an important ingredient, and some recent developments concerning the efficient calculation of corresponding cross sections have been shown. Finally, another rectification included in modern tools, consists in a better understanding and modelling of hadron (especially B and D) and τ decays and in the simulation of non-trivial quantum interference effects.

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